51. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

PROCEEDINGS 11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
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Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

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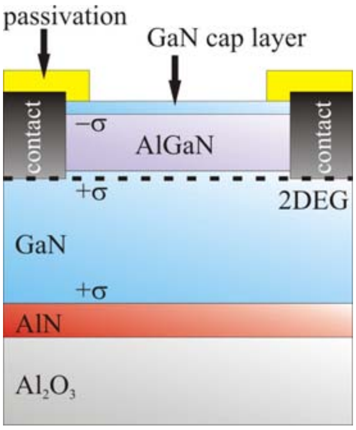
AlGaN/GaN-sensors for monitoring of enzyme activity by pH-measurements

Group-III nitrides are pyroelectric materials, i.e. they show spontaneous and piezoelectric polarization. The difference of polarization within an AlGaN/GaN-heterostructure leads to local fixed polarization charges screened by the accumulation of free carriers close to the interface [1]. The carrier density of the two-dimensional electron gas (2DEG) is very sensitive to any manipulation of surface potential. Therefore this heterostructure can be used to develop sensors for the detection of ions, gases, and polar liquids [2]. The sensor structure is shown in Fig. 1. The optical transparency of the GaN-based sensors can be used to combine electrical with optical measurements with wavelengths above 360 nm. In this work the enzyme activity and reaction kinetic of a lipase assay were monitored by continuously measuring of pH-value with novel optimized GaN-based sensors.

From the technological point of view the heterostructures grown by PIMBE were optimized by changing the material composition and the thickness of the AlGaN-barrier influencing the onset of depletion of electrons from the 2DEG during CV-measurements and later in sensor applications. The beginning of depletion is an important parameter developing sensors for different applications. The optimization process was supported by computer simulations of AlGaN/GaN-heterostructures shown in Fig. 2. The influence of barrier thickness and surface potential on the electrical behaviour of sensors was investigated. A barrier thickness of around 12 nm and an Al-content of 25 % were well suited for pH-measurements.

The sensitivity of AlGaN/GaN-heterostructures caused by changing the surface potential were already demonstrated for H^+-ions [3], cell action potential [4], and even for immobilized proteins [5]. GaN-based sensors were calibrated with different buffer solutions. At room temperature the sensitivity of pH-sensors is almost 59 mV/pH showing Nernstian behavior. In order to determine the sensitivity and the operation point of the sensors I_{DS}-U_{Ref}-characteristics were measured at different pH-values. The



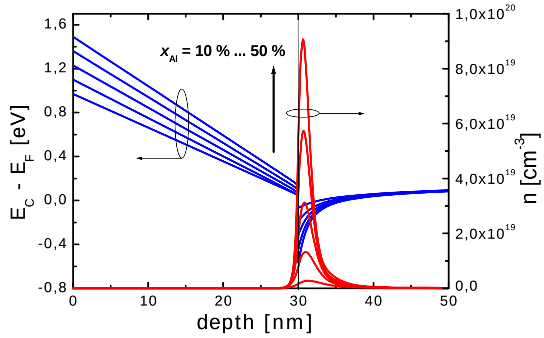


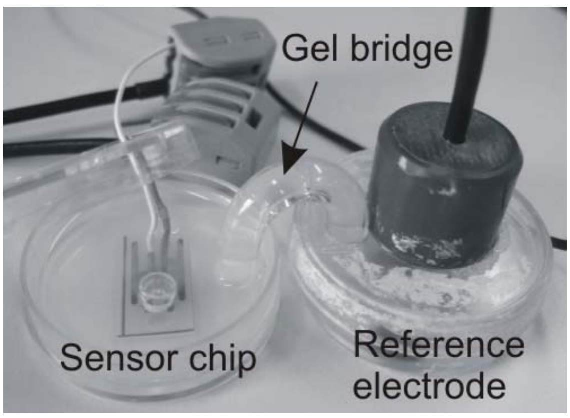
Figure 1: Schematic view of an AlGaN/GaN pH-sensor.

Figure 2: Theoretical calculation of conduction band and carrier concentration with varying Al-content.

measured reference potential showed a linear dependence from the pH-value.

For monitoring of an enzymatic lipase assay and of reaction kinetics by continuously measuring the pH-value the AlGaN/GaN sensor were connected by a gel bridge to a micro reference electrode as it is shown in Fig. 3. Lipases are the most versatile biocatalysts used for many biotransformation reactions such as alcoholysis, acidolysis, and hydrolysis. In our experiments lipase reacted with 4-nitrophenyl caprylate producing caprylic acid. The change in pH value caused by caprylic acid is shown in Fig. 4. Different enzyme concentrations were measured resulting in different reaction velocities. The AlGaN/GaN-sensors are well suited for these measurements with a total reaction volume of about 35 µl.

Another application is monitoring the enzymatic release of acetate by histone deacetylases (HDAC) by measuring changes in pH in order to identify new inhibitors for this actual and promising target enzyme in cancer therapy. Utilisation of this pH-sensor would give the chance to identify these inhibitors directly without other (bio-)chemical reactions in a homogeneous format by continuously monitoring the target enzyme.



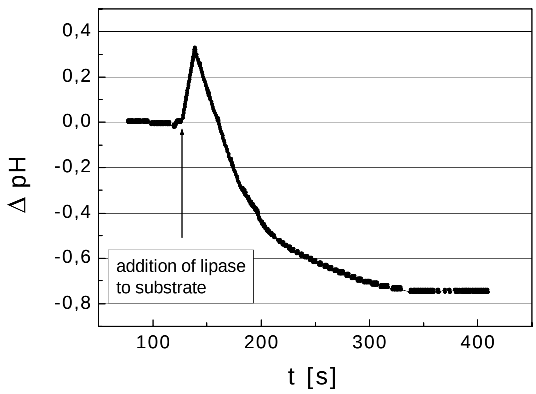


Figure 3: Measurement setup for lipase assay.

Figure 4: Change of pH after adding lipase.

AlGaN/GaN heterostructures were used to measure the change in pH value during a lipase bioreaction. GaN-based pH-sensors are well suited for monitoring lipase related bioreactions and offer the possibility to a combined electrical-optical measurement.

This work was supported by the Thuringian ministry of culture (TKM) and the European Union (EFRE program: B 678-03001, 6th framework program: GaNano NMP4-CT2003-505614).

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